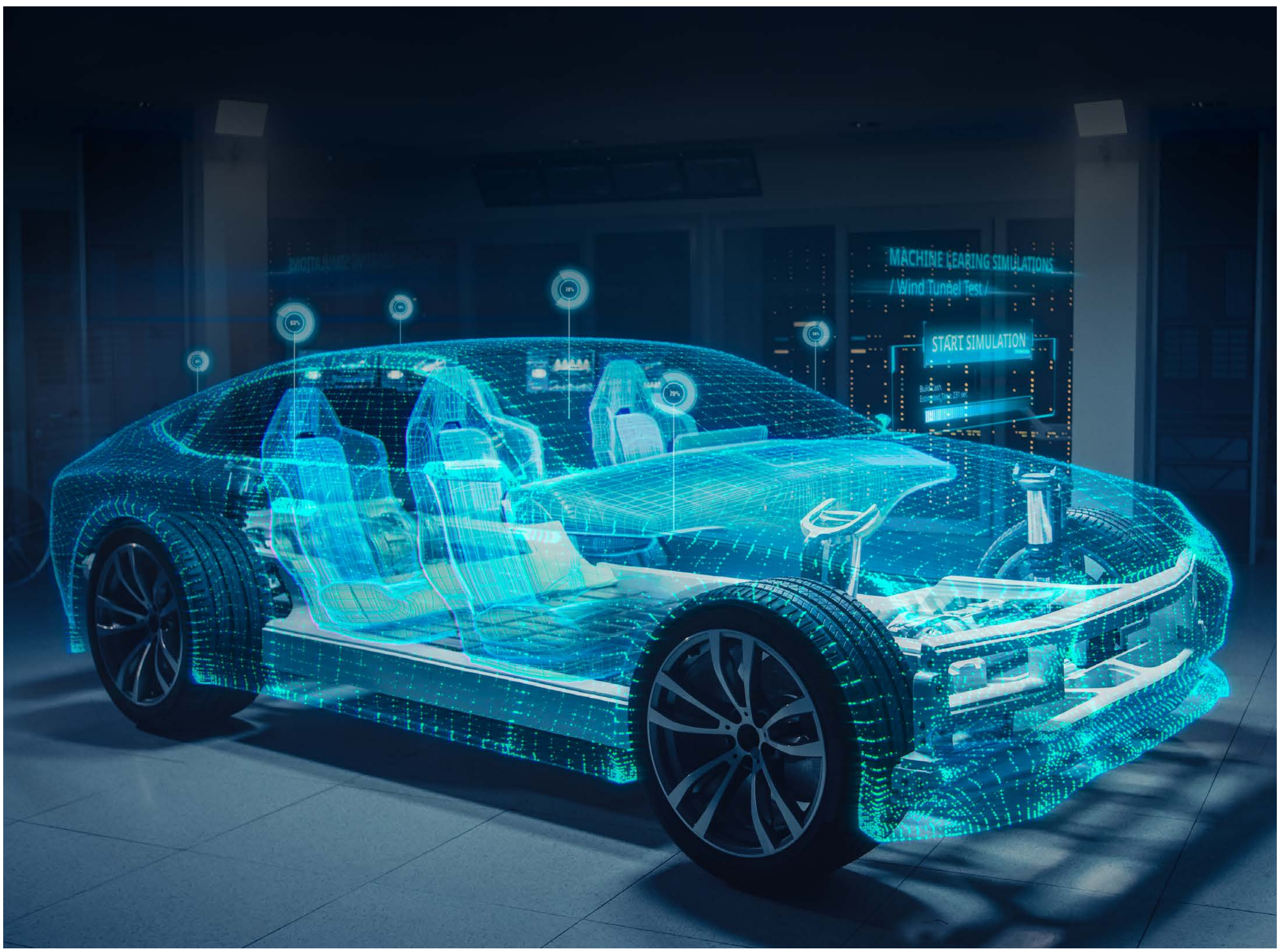
WHITEPAPER

# SEALING, PROTECTION AND ELECTROMAGNETIC COMPATIBILITY (EMC) DESIGN CONSIDERATIONS IN E-MOBILITY APPLICATIONS

**Performance Materials: An underlying solution to complex electrification design requirements.**

*Provides insulation, sealing, protection, and shielding for critical components in electric vehicle (EV), hybrid vehicles and charging infrastructures.*



## INTRODUCTION

EV and hybrid applications often require manufacturers to design robust, resilient, and lightweight vehicles that address the performance demands of the transportation vehicles market. In the industrial space, this is further compounded by the need to operate in harsh conditions such as heavy rain, snow, and extreme temperature changes on a daily, constant, and seasonal basis.

But that's not all. Major market needs around safety, connectivity, and efficiency are also impacting manufacturing specifications in the EV and hybrid vehicle space.

Design engineers must address the voltage, current, sealing, vibration, chemical compatibility, and temperature challenges associated with manufacturing all types of EV and hybrid vehicles. This means choosing protective products that can work within increasingly complex designs, as well as withstand the harsh environments inherent to vehicle operation.

Increasingly, it also means vehicles manufacturers must choose a component provider that not only understands current and future market demands but offers a breadth of products that address a range of needs and are backed by decades of superior performance and reliability.

Heat shrink tubing is a solution to support these performance challenges—TE Connectivity (TE) is the choice provider. TE's Raychem heat shrink tubing products have proven to be the optimal solution for insulating components against heat and electric current, providing strain relief for connectors and splices, and protecting and sealing against water ingress, chemicals and abrasions. Versatile in solving design challenges efficiently, heat shrink tubing has also shown to outperform tape, glue and glass alternatives, particularly when it comes to impact resistance and operating in harsh environments.

In addition to protecting and sealing critical components, product designers need to understand that all active electronic devices have the potential to emit electromagnetic radiation in the architecture of the vehicle and therefore also need to consider electromagnetic interference (EMI) shielding products to protect critical electronic components and systems from EMI. This is particularly true for designing highly integrated architectures where high voltage and high current systems are in close proximity to low voltage signal lines.

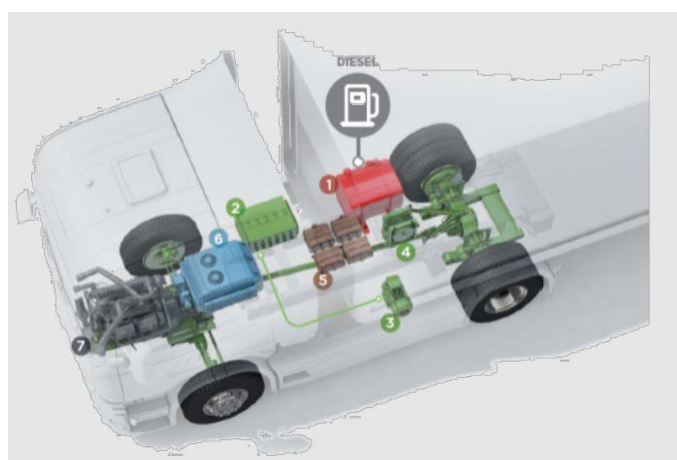
This white paper describes the electrification and electromobility (e-mobility) impact on vehicles architectures including EMI and protection of electric components design considerations. TE's technology and portfolio address these critical design and connectivity challenges the industry is experiencing. TE is a leading provider of heat shrink tubing, offering a wide portfolio of products to address an array of vehicles manufacturing related needs.

### E-MOBILITY ARCHITECTURES

Not only are the use cases for electric and hybrid vehicles equipment complex and diverse, so are the possible vehicle architectures being developed to enable cleaner transportation. Today's vehicles whether industrial, commercial or consumer, are typically powered by internal combustion engines driving two or more wheels through a transmission.

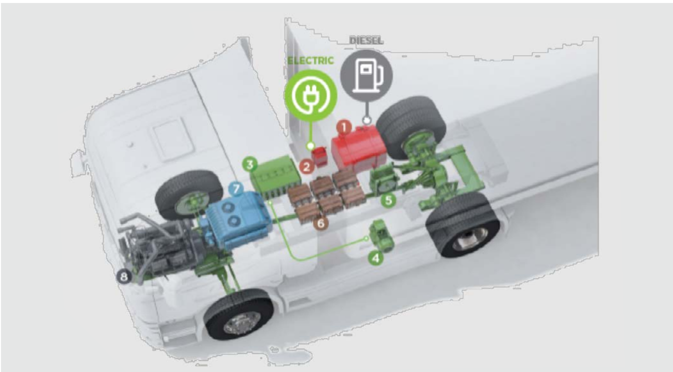
They primarily use gasoline, diesel fuel, or in some cases compressed natural gas (CNG). While industry manufacturers have taken steps to improve fuel consumption and reduce emission, including the introduction of 48V mild hybrid approaches, more needs to be done. Legislation and widening diesel bans are magnifying the need for reduced emissions. As a result, vehicle manufacturers are accelerating development away from internal combustion engines (ICE) and focusing more on architectures incorporating electric motors. The approaches they are actively pursuing may be summarized in four categories:

**CONVENTIONAL HYBRIDS** These hybrid architectures have conventional engines and electric motors and batteries, but cannot be conventionally plugged into the power grid. They derive their power from gasoline and diesel, and thus are not categorized as electric vehicles. A mild hybrid typically utilizes a small electric motor and 48V battery combined with an internal combustion engine (ICE)E allowing for assisted acceleration and regenerative braking. A strong, or parallel hybrid, will generally consist of a larger electric motor and battery combined with a downsized ICE utilizing regenerative braking and electric motor drive.




1. Fuel Tank
2. LV PDU
3. Electric Motor
4. Gearbox Generator
5. Battery
6. Auxiliaries
   - -Ac System
   - -Pumps
   - -Heater
   - -Blower
7. Ice

**PLUG-IN HYBRIDS** Plug-in hybrid electric vehicles (PHEVs) are similar to battery electric vehicles, typically with a smaller battery, but also have a conventional gasoline or diesel engine. Although not as clean as battery electric or fuel cell vehicles, plug-in hybrids produce significantly less pollution than their conventional counterparts. Series PHEVs are typically referred to as range extenders, with the ICE's primary purpose to charge the battery on the go.




**1. Fuel Tank**

**2. Charging inlet**

**3. LV PDU**

**4. Electric Motor**

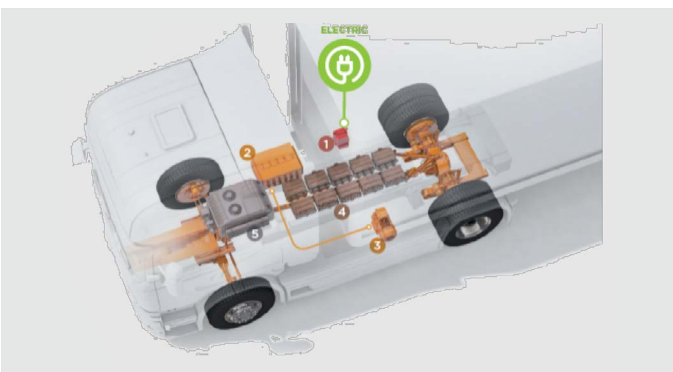
**5. Gearbox Generator**

**6. Battery**

**7. Auxiliaries**
- **-Ac System**
- **-Pumps**
- **-Heater**
- **-Blower**

**8. Ice**

**BATTERY ELECTRIC VEHICLE (BEV)** BEVs use stored energy in a battery to drive electric motors. The operating voltage can be as low as 48V and as high as 850V (or higher), depending upon the application. This offers them increased efficiency and, like fuel cell vehicles, allows them to drive emissions-free when the electricity comes from renewable sources. BEVs use existing infrastructure to recharge and are increasing the demand on the energy grid.




**1. Charging inlet**

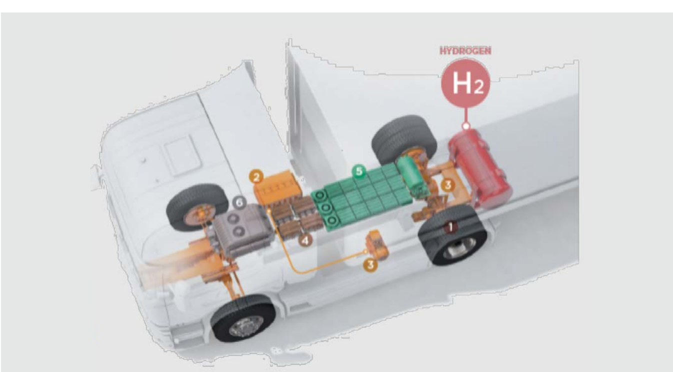
**2. HV PDU**

**3. Gearbox Generator**

**4. Battery**

**5. Auxiliaries**
- **-Ac System**
- **-Pumps**
- **-Heater**
- **-Blower**

**HYDROGEN FUEL CELL ELECTRIC VEHICLE (FCEV)** The source of power is an on-board fuel cell that generates electricity from hydrogen, either to charge a battery or to drive the electric motors. FCEVs require a hydrogen fueling infrastructure which is not always emissions-free and not broadly available today.




**1. Hydrogen Tank**

**2.HV PDU**

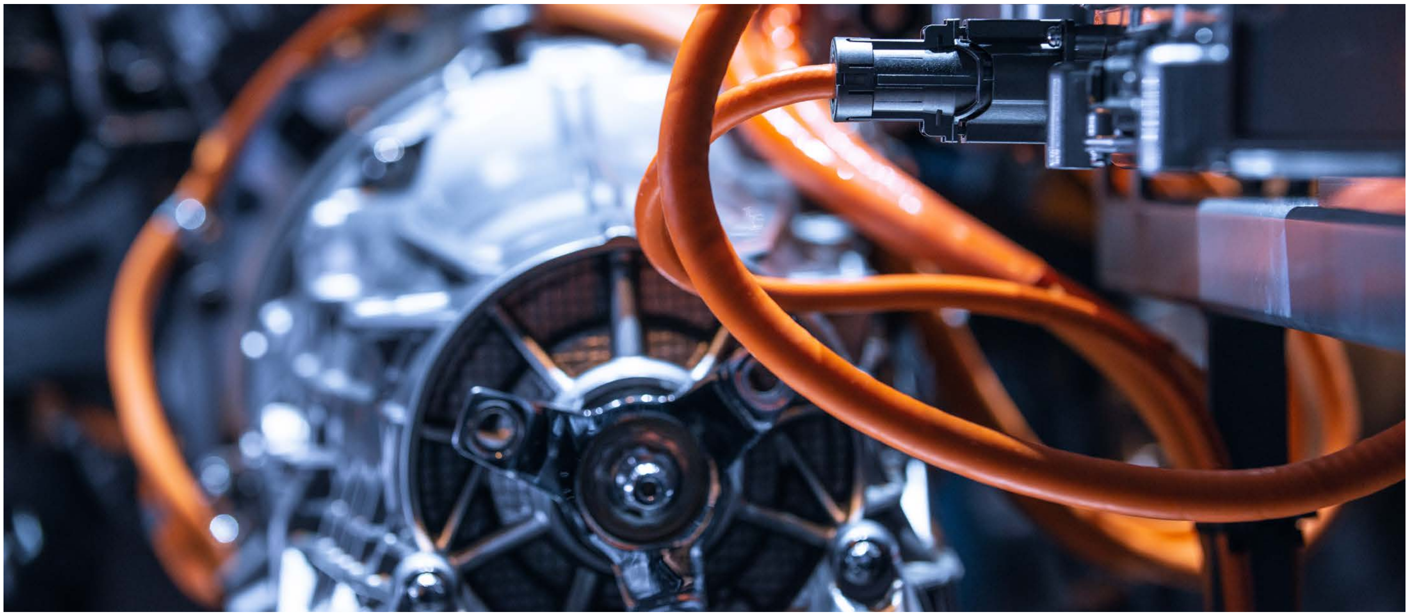
**3. Electric Motor**

**4. Battery**

**5. Fuel Cell**
- **-Cell Stack**
- **-Blower**
- **-Gaas Injector**
- **-Air Coompressor**
- **- Sensors**

**6. Auxiliaries**
- **-Ac System**
- **-Pumps**
- **-Heater**
- **-Blower**

## ADDRESSING THE HIGH VOLTAGE INSULATION CHALLENGES



Electrical insulation materials can be in solid, liquid and gas form dependent on the given application. For high voltage transmission, air becomes the dominant insulation material for overhead power lines, whilst gases such as sulfur hexafuoride (SF6) are used for switch gear applications as SF6 helps suppress internal discharge activity. Modern cable insulation systems tend to be solid polymeric based systems which may also be cross-linked during production.

Solid polymeric materials are used in many electrical applications and appliances, and this is either thermoplastic in nature (i.e., polyethylene, polypropylene, ethylene vinyl acetate (EVA), ethylene methyl acrylate (EMA), etc.) or thermosetting type resins like epoxy (e.g. for PCB's) or polyurethane-based systems. For higher fidelity or more challenging environments, polytetrafluoroethylene (PTFE) or polyvinylidene fluoride (PVDF) (e.g., Kynar brand) solutions could be considered, but typically at increased cost. Silicone rubbers are also commonly used for higher temperature type applications along with polyimide-based films (e.g. Kapton brand).

Failure modes can be split into 5 major categories all associated with energy, and these are detailed in Table 2. (refer to HV Whitepaper)

| Base Polymer | Characteristics |
|---|---|
| PVDF | • Pros - Excellent chemical resistance, abrasion resistance, flame resistance and temperature and UV stability<br>• Cons – Cost |
| PTFE | • Pros – Excellent chemical resistance, low friction, excellent insulation and dielectric properties (I.e. low loss, low conductivity)<br>• Cons – Cost |
| Polyethylene (PE) | • Pros – Commonly used, excellent electrical insulation and dielectric characteristics, good chemical resistance (not to organic solvents), moderate mechanical properties, processability, cost, hydrophobic<br>• Cons – Low dielectric constant, relatively low operational temperature range < 135°C |
| Polypropylene (PP) | • Pros – Good impact strength and mechanical properties (good energy dispersion under impact conditions), higher melt temperature than PE, good insulation properties and low dielectric loss, good chemical resistance (not to organic solvents)<br>• Cons – Low dielectric constant |
| Ethylene vinyl acetate (EVA) | • Pros – Good adhesive properties, very flexible, also acts as processing aid when compounded with other polymers in copolymer systems<br>• Cons – Very low melt temperature, relatively poor electrical insulator, prone to moisture absorption |
| Ethylene methyl acrylate copolymer (EMA) | • Pros - Accept high level of fillers / additives, thermal stability, flexibility and adhesion<br>• Cons – Moisture absorption, temperature limited to 135°C |
| Polyethylene Terephthalate (PET) | • Pros – Good electrical properties (especially in thin film form), good thermal stability<br>• Cons – Moisture absorption |

Table 1. Common polymers used for electrical applications including heat shrink viability.

| Energy Type | Energy Sub Type | Failure Mode |
|---|---|---|
| Thermal | High Temperature | • Thermal degradation due to thermal induced chemical reaction or decomposition<br>• Mechanical failure due to changes of material property |
| | Low temperature | • Electro-thermal failure due to increased current flow at elevated temperature<br>• Combustion / flammability<br>• Loss of flexibility leading to cracking,<br>• Loss of dimensional conformity or sealing capability |
| Mechanical | Shock<br>Vibration<br>Compression (constant)<br>Tension (constant)<br>Shear<br>Bending / flexing<br>Abrasion | • Fracture / splitting<br>• Mechanical fatigue and fracture<br>• Creep, fracture, loss of dimensional conformity<br>• Creep, yield loss of dimensional conformity<br>• Fatigue / creep, cracking, fracture, delamination<br>• Mechanical fatigue and fracture / splitting<br>• Loss of surface material leading to failures in other categories |
| Electrical | AC<br>DC<br>High Voltage<br>RF | • Heating, fire (mains current levels due to dielectric and conduction heating)<br>• Heating, fire (mains current levels – conduction heating)<br>• Dielectric / insulation breakdown, Partial discharge, electrical surface tracking and flashover (see 3)<br>• Localised surface heating and thermal degradation |
| Chemical | Water and Moisture<br>Organic fluids / solvents<br>Oils<br>Petrochemicals<br>Corrosive | • Failures associated with increased electrical conductivity (3, 12, 13, 14, 15)<br>• Dimensional distortion and non-conformance<br>• Dimensional distortion and swelling, possible dissolving and loss of mechanical integrity<br>• Dimensional distortion and swelling / chemical compatibility<br>• Chemical attack of material leading to removal of insulation system and mechanical integrity |
| Radiation | UV<br>X-ray<br>(α, β, Gamma, neutron) | • Embrittlement, discolouration, degradation<br>• Bond scission and loss of material integrity over time Not considered in this paper |

Table 2. Major failure modes associated with polymer insulation systems

When it comes to high-voltage applications, it is important to choose a heat shrink tubing material that can withstand the high voltages involved without breaking down or failing. Here are some of the best high-voltage heat shrink tubing materials:

- **Polyolefin heat shrink tubing:** Polyolefin tubing can be a good choice for high-voltage applications up to around 2.5kV. It offers excellent electrical insulation and resistance to chemicals and UV radiation, making it suitable for a wide range of applications. The voltage range is really limited by the level of additives utilized to achieve specified flammability properties and increased thermal stability.
- **Silicone tubing:** Silicone tubing is highly resistant to high temperatures and can typically withstand voltages up to around 10kV. It is often used in high-temperature applications such as automotive wiring and electronic equipment.
- **Ethylene propylene diene monomer (EPDM) heat shrink tubing:** EPDM is an exceptionally durable and flexible material that can withstand relatively high temperatures (up to 150°C) and is resistant to a wide range of chemicals and environments. It is often used in high voltage applications up to 35kV, such as in power distribution and electrical equipment where thicker walls are possible due to the inherent material flexibility, consequently it is also effective at lower temperatures (e.g. -40°C).
- **Fluoropolymer heat shrink tubing:** Fluoropolymer tubing made from materials such as PVDF is highly resistant to chemicals and can withstand elevated temperatures and high voltages. It is often used in harsh environments such as chemical processing plants and aerospace applications.
- **PVC heat shrink tubing:** PVC tubing can offer good electrical insulation and can withstand voltages up to around 2kV. However, it may not be the best choice for high temperature applications, as it can become brittle and break down over time.

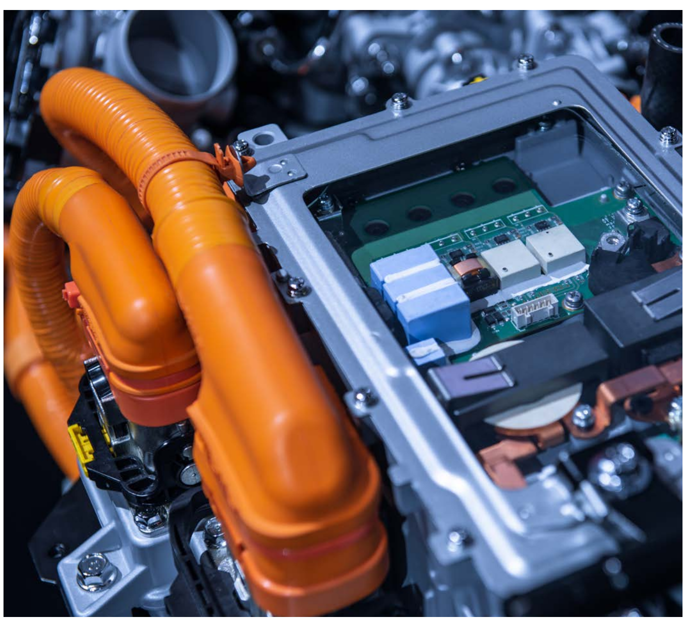
The best high voltage heat shrink tubing material for a given application depends on several factors, including the specific voltage and temperature requirements, the level of chemical exposure, and other environmental factors. It is important to choose a high-quality tubing material and follow proper.

installation techniques to help provide a safe and reliable electrical system.

## IMPORTANCE OF SEALING AND PROTECTION OF EV AND HYBRID VEHICLE COMPONENTS FOR SAFETY

The use of heat shrink tubing can offer numerous substantial advantages for electric vehicle batteries. One key benefit is its ability to furnish dependable protection against a variety of challenging environmental conditions. Heat shrink tubing can help shield the battery, along with its associated wiring and cables, from factors such as humidity, oils, grease, chemicals, and other substances, enables optimal performance over an extended period. Additional merits encompass:

- **Insulation Enhancement:** Heat shrink tubing adds an extra layer of non-conductive insulation between the battery and potential contact points. The augmented insulation thickness not only facilitates improved energy transmission but also can introduce an extra layer of safety.
- **Cable Stress Mitigation:** The utilization of heat shrink tubing can provide enhanced mechanical support to wiring and cables, safeguarding them from exposure to environmental elements. This protective layer can help cables remain free from stretching or confinement in areas with limited space.
- **Corrosion Protection:** While the metals used in cables and wiring can be engineered to resist corrosion, employing a reliable insulating material is crucial for more comprehensive protection. Heat shrink tubing can prove highly effective in shielding batteries and wires by protecting against corrosion.



## ELECTRIC VEHICLE CHARGING STATIONS: COMPONENTS AND ELECTRICAL DESIGN CHALLENGES

As the world continues to make the shift to e-mobility, there is an increasing demand for charging infrastructure, and it is becoming part of our daily life.

Charging your car at home or at work requires standard Alternative Current (AC) home charging units and workplace charging units. AC charging units can be economically effective and can be installed with great flexibility.  Direct Current (DC) charging stations can have a very quick charging rate as little as 30 minutes. The rapid, global growth of EVs requires the development of a charging infrastructure that is faster, safer, smaller and more flexible, which creates design challenges for engineers around the world.

Electric vehicle supply equipment (EVSE) are intricate systems comprising a variety of electronic components. These components function in unison to provide safe and efficient charging of electric vehicle batteries. Much like other advanced, high-power electronic devices, these EVSE stations can encounter issues related to thermal management and EMI shielding that need to be addressed for proper and efficient operation. In this article, we will delve into the key components of EV charging stations and propose solutions for common electrical design challenges.

## E-MOBILITY CREATING MORE ELECTROMAGNETIC COMPATIBILITY (EMC) CHALLENGES

Despite the strides in innovation, modern electrified drivetrains introduce a new and intensified electromagnetic environment within vehicles. Operating at voltages in the hundreds, currents in the hundreds of Amperes, and electric motors exceeding 100 kW, these systems usher in unprecedented levels. Electrified drivetrains and operating at high voltage occur in an industry that historically invested heavily in optimizing combustion technologies, now necessitating a comprehensive transition to electrified drivetrains.

In the realm of e-mobility, EMC assumes a pivotal role. While EMC tests have been mandatory for conventional electrical devices for years, they are equally crucial for vehicle components. Components such as inverters and motors play key roles in impacting electromagnetic compatibility, as the potential interference created by such components can significantly impact other electronic vehicle components.

High-voltage switching can cause EMI, disrupting communications and signals on low-voltage circuits. For a phone or laptop computer, failure is a terrible inconvenience. Failure of a vehicle or a piece of heavy-duty equipment can mean a loss of productivity — resulting in an impact to one's business, or in a worst-case scenario, can cause serious injury or death. Safe operation is critical. Charging, maintenance, and crash mitigation must all be done in a safe manner. The complexity of EV architectures and basic operating principles is closer to airplanes, energy grids, and consumer electronic devices than it is to ICE vehicle approaches.

When it comes to electric vehicles, EMC is often an afterthought in the design process but can have a significant impact on performance and delay time to market by not meeting industry compliance requirements. EMC design involves three primary domains:

- **Emission:** This pertains to the inadvertent or deliberate release of electromagnetic energy into the surrounding environment.
- **Susceptibility:** This concerns the probability of electrical equipment malfunctioning or failing to operate as intended when exposed to electromagnetic emissions.
- **Coupling:** This focuses on the mechanism by which electromagnetic energy interfaces with electrical equipment.

Analyzing these three aspects can aid engineers in discovering the most efficient approaches to minimize the impact of electromagnetic emissions in electric vehicles (EVs). EMC components will continue to play a pivotal role in the safety and reliability of electric vehicles.

## COMPLIANCE WITH EMC STANDARDS

Designing for EMC is becoming increasingly important as technology advances. With the emergence of 5G communication specifically, many new systems will need to meet EMC legislation and regulations, and radio frequency interference (RFI) shielding of the enclosures and components in these systems effectively will become a requirement. EMC is regulated by numerous bodies across the world, and each industry sector has specific EMC standards. Although not exhaustive, Table 1 lists common EMC standards by application. A more comprehensive list, published by Interference Technology, can be found at https://learn.interferencetechnology.com/2022-emc-testing-guide/. As a best practice, design engineers should consult the appropriate guidance in their region and industry before beginning a project.

| Application/Industry | EMC Standard |
|---|---|
| **Automotive components** | IEC CISPR 25<br>ISO 11451<br>ISO 11452<br>ISO 7637<br>SAE (multiple numbers) |
| **Commercial equipment** | FCC Part 15 class B<br>IEC 61000-6-1 (generic)<br>IEC 61000-6-3 (generic) |
| IEC: International Electrotechnical Commission; ISO: International Organization for Standards; SAE: Society of Automotive Engineers; FCC: Federal Communications Commission | |

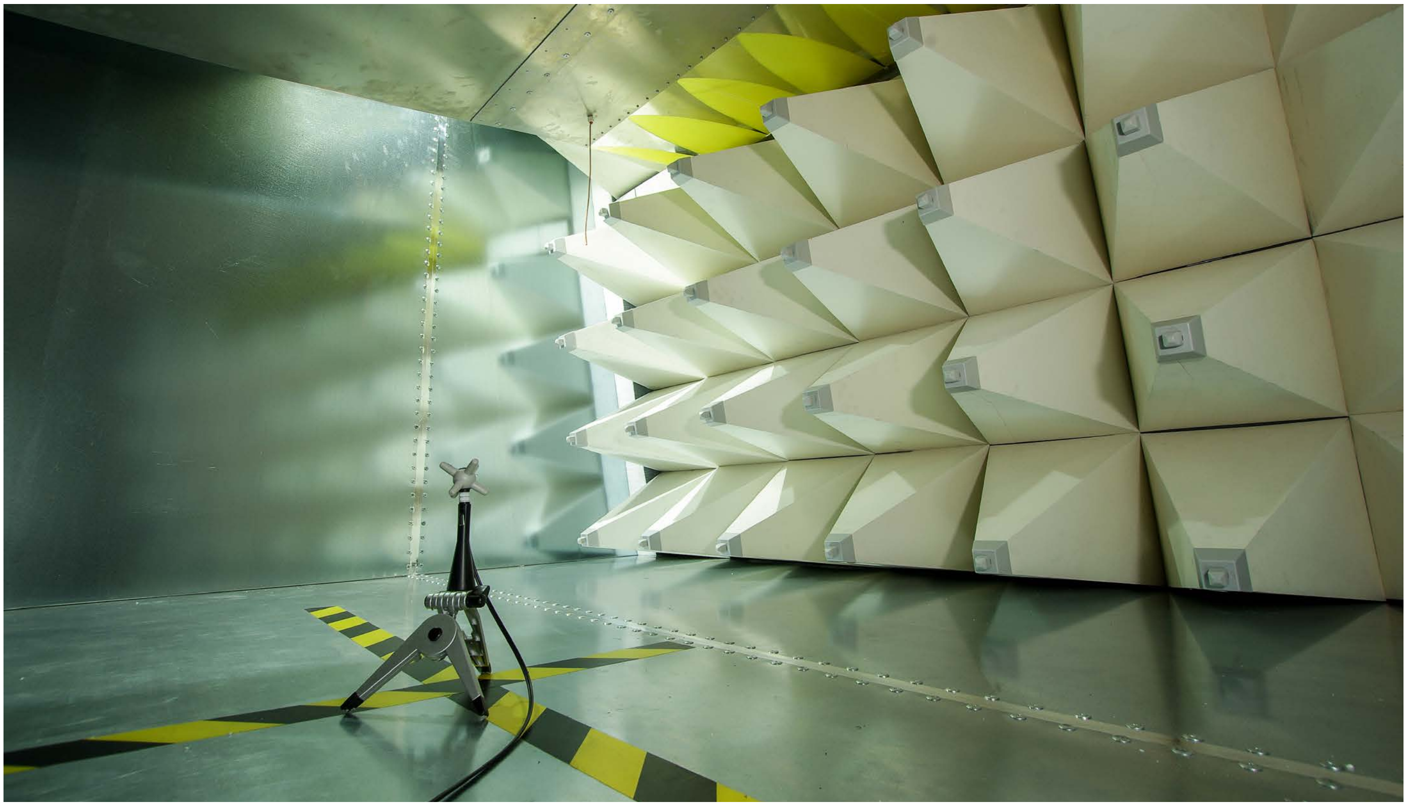
Table 3. Common EMC Standards in Electromobility Applications

## EMC TESTING

EMC must be addressed before any electronics product comes to market, regardless of industry or application. EMC testing measures a product's radio frequency (RF) emission levels and its immunity to RF emissions. Results from the testing environment will give engineers an indication of whether the product will produce EMI in the real world[x].

### There are three main steps to EMC testing:

- **Identify the appropriate standards.** As previously stated, applicable standards vary across products, applications, and geography. Either contact a test house and ask which standards apply or fully research the standards yourself before beginning any testing activities.



- **Perform pre-compliance testing.** To assess that your product is adequately addressing EMI and meets standards for energy emissions before formal testing, you will ideally want to test within an anechoic chamber or an RFI shield enclosure. Fully EMC compliant testing equipment, such as EMI receivers, can be rented for these purposes. Detailed instructions for setting up pre-compliance testing in house, an overview of the necessary equipment, and a supplier guide are available from established sources such as at https://learn.interferencetechnology.com/2022-emc-testing-guide/.
- **Select an EMC test lab.** Make sure that the lab you select is accredited by A2LA for ISO/IEC 17025. Crucial when placing your product in market, this accreditation will validate your testing. Expect a lag of at least several months when booking the lab and plan your pre-compliance testing accordingly.

Several basic tests are performed to assess a product's EMC. These include radiated immunity and emissions and conducted immunity and emissions. Testing for radiated immunity gauges the product's performance when it is exposed to electromagnetic energy within its environment. Testing for radiated emissions evaluates the amount of electromagnetic disturbance caused by the product. Conducted immunity testing measures the test product's response to electromagnetic energy that originates with another product and is conducted via a cable or conductor to the test product. Conducted emissions testing analyzes the electromagnetic energy that travels from the test product along a conductor to another product. A variety of specialized equipment is available for the in-house performance of each of these tests. Conducting these tests in house before sending a product to a lab for EMC certification can allow for the fine-tuning that may prevent a product from failing on the first attempt at certification.

## EMI SHIELDING: A MECHANICAL FIX TO AN ELECTRICAL PROBLEM

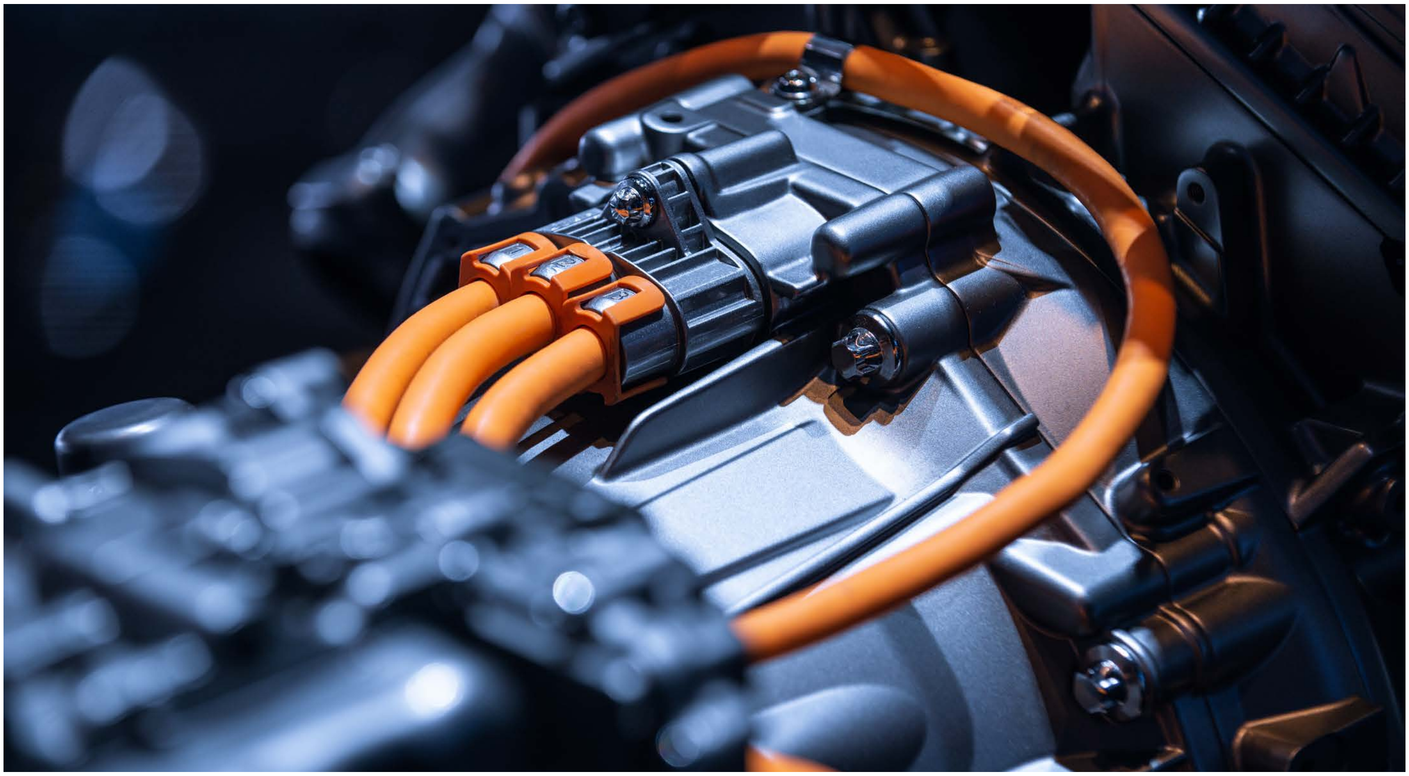
Electronics engineers are very familiar with this and will consider in their design good board layout, filtering, grounding, signal integrity etc. to try resolving EMI at its source. However, shielding of the enclosure is just as important and can solve the problem of radiated emissions and susceptibility. Shielding is a mechanical fix for an electrical problem and the enclosure design engineer should be aware of the types and different attributes of gaskets available and provide enough land area on the enclosure seams, doors etc. to fit the gasket. There are 4 main gasket types available:

- **Knitted wire mesh** can be fitted in grooves or surface mounted when bonded to a carrier. There are four wire options available to address shielding and corrosion issues. When bonded to a carrier, knitted wire mesh offers good dust and moisture seal, often preferred for rugged military applications as it provides good electromagnetic pulse (EMP) protection as the gasket can carry high currents.
- **Conductive elastomers** have conductive particles loaded into silicone or fluorosilicone. Many different particles are avail-able from carbon up to pure silver, and the most popular are nickel coated graphite and silver-plated aluminum. All, apart from carbon, offer good all-round shielding and high performance at many frequencies. Nickel coated graphite is very cost effective being a factor of 3-5 times less expensive than silver-plated aluminum, and yet still offers shielding effectiveness similar to that of silver-based products. The conductive elastomer compound can be extruded in continuous lengths in many different profiles and can be molded as a sheet and die cut or molded as a component. Conductive elastomer O-rings make for a very cost-effective EMI seal and are popular in defense and aerospace applications due to their small profile size, low weight and high performance.
- **Form in place** is a conductive elastomer, being conductive silicone in liquid form for depositing direct to enclosure hardware. Particularly suited for use on small enclosures due to the narrow land widths, different fillers are available simi-lar to that of conductive elastomers. This type of gasket offers a dust and moisture seal. It is not suitable for opening and closing of the enclosure.
- **Oriented wire** in silicone are nickel-copper alloy or aluminum wires vertically oriented in solid or sponge silicone. Available as flat sheet material for surface mounting, the gasket can be die cut to shape or can be fabricated from strips to make a picture frame gasket, and provides a good EMI and environmental seal. This type of gasket is very popular in defense applications as it offers very low contact resistance as the wires penetrate the mating surface.
- **Conductive fabric over foam** gaskets are good for commercial applications, and most are stick on surface mount and are soft and compliant making good cabinet door seals. These can be very popular in laptop computers, gaming machines etc. for grounding.
- **Beryllium copper fingers** are good in shear/wiping applications and will be seen on doors for shielded rooms, and they offer good all-round high performance and are available in many plated finishes to enhance shielding and address galvanic concerns.

## TE'S RAYCHEM HEAT SHRINK TUBING PRODUCTS: APPLICATIONS FOR HARSH AND RUGGED ENVIRONMENTS

As design engineers address the sealing, vibration and temperature challenges associated with many harsh environment applications, it's important to understand the benefits of heat shrink tubing:

- **Versatility and Durability:** Heat shrink tubing use can improve the ability to keep out moisture, harsh chemicals and mechanical interference. Heat shrink tubing also can provide strain relief, electrical insulation, mechanical protection and environmental sealing for applications such as back-end connector sealing, breakouts, connector-to-cable transitions, and is especially useful in cable harnesses.
- **Quick Installation/High-Tech Performance:** Heat shrink tubing often has a faster application time than other products resulting in better performance. For example, when compared to tape, heat shrink tubing has been shown to shorten application time (from 180 seconds to 45 seconds), improve yield (from less than 90% to over 98%) and provide a higher operational temperature rating (125°C compared to 105°C.)
- **Easier Installation:** When heated, heat shrink tubing conforms to the size and shape of the substrate beneath, enabling quicker and easier installation. Its high expansion ratio of up to 8:1 can also enable users and technicians to repair most damaged cable jackets without removing other components such as connectors.
- **Safety:** Heat shrink tubing products can help maximize safety. When selecting heat shrink tubing, one should consider variables such as thickness of the tubing to secure extra protection, various colors for easy identification, and various levels of flame-retardancy to meet UL VW-1 flammability standards.

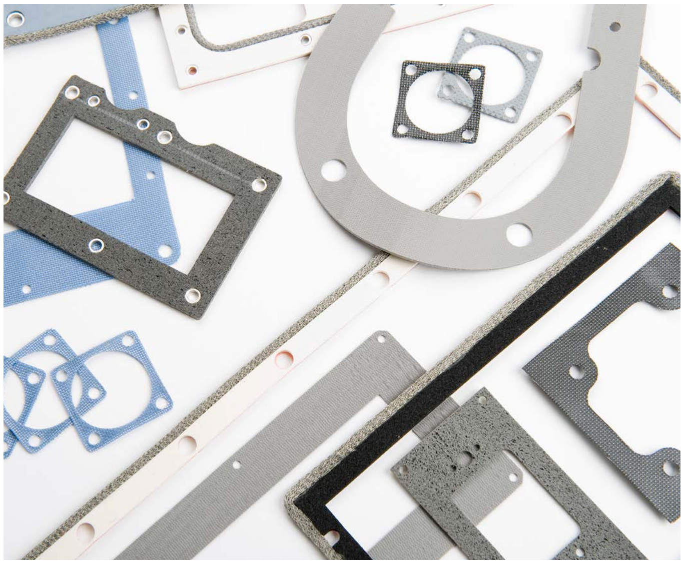


- **Reliable, Robust Cross-linking Technology:** Cross-linking technology modifies the molecular structure of a polymer, allowing the tubing to withstand high temperatures without melting — a critical factor such as in harsh industrial commercial transportation environments. Heat shrink tubing can provide a complete seal and its high mechanical strength makes it more resistant to impacts and abrasions.
- **Offered in Single Wall and Dual Wall Heat Shrink Tubing:** Single wall shrink tubing provides superior insulation strain relief and protection against mechanical damage and abrasion versus taping and molding in place. Dual wall tubing should be considered the top choice over taping, molding and potting for any circumstance where corrosion protection and sealing are required.

## TE'S EMI SHIELDING PRODUCTS: OPTIMIZE ELECTRICAL, MECHANICAL PERFORMANCE AND COMPLIANCE.

As design engineers address electromagnetic compatibility, which directly affects the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to and from other equipment in that environment, it is important to understand the benefits of critical EMI shielding design considerations:

- **Signal Integrity:** EMI shielding materials help maintain the integrity of signals within electronic devices. By preventing external interference, these materials help ensure that signals remain clear, stable, and unaffected by external electromagnetic sources. This is particularly important in high-frequency and precision electronic systems.
- **Compliance with Regulatory Standards:** Many industries and applications have strict regulations regarding EMI. The use of EMI shielding materials helps electronic devices and systems meet these regulatory standards, so they operate within acceptable EMC limits.
- **Reduced Cross-Talk:** EMI shielding materials can minimize cross-talk, which is the undesired electromagnetic coupling between adjacent components or circuits. By containing and redirecting electromagnetic fields, EMI shielding materials contribute to a cleaner and more isolated signal environment.
- **Improved Reliability:** Shielding sensitive components from external interference enhances the overall reliability and performance of electronic systems. This is particularly important in critical applications such as medical devices, aerospace, telecommunications, and automotive electronics.



- **Enhanced Safety:** EMI shielding can also be crucial for safety reasons. In certain environments, electromagnetic interference can disrupt the proper functioning of critical electronic systems, leading to safety hazards. Shielding materials help mitigate these risks by providing a protective barrier.
- **Longevity of Electronic Components:** EMI shielding materials contribute to the longevity of electronic components by protecting them from the potentially damaging effects of electromagnetic interference. This can lead to increased durability and a longer lifespan for electronic devices.
- **Design Flexibility:** EMI shielding materials come in various forms, such as conductive elastomers, wire mesh, gaskets, O-rings, fabric over foam, etc. This diversity allows designers to choose the most suitable material for their specific application, providing flexibility in design and manufacturing processes.

## KEY TAKEAWAYS

Manufacturers face countless design requirements to meet the most rugged of performance demands, as well as new challenges brought on by ever-changing market trends and evolving market needs like the rise of e-mobility and high voltage electrical sealing and protection. TE's Raychem brand heat shrink tubing solutions are designed to help manufacturers meet a wide range of needs and conditions.

Within the realm of electric vehicles, EMC and EMI protection emerge as playing a crucial role in providing reliable performance, maximizing safety, and facilitating compliance with regulations. Employing shielding, filtering, grounding, and bonding techniques, these protective measures can effectively mitigate interference, creating a harmonious electromagnetic environment within EVs.

The ongoing evolution of electric vehicles brings forth a parallel evolution in challenges related to EMC and EMI protection. Future trends are poised to witness the emergence of more sophisticated shielding materials, refined filtering techniques, and improved system integration. Successfully addressing these challenges can be paramount to the smooth functioning of electric vehicles in an increasingly electrified world.

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